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Comparison of Key Aroma Compounds in Cooked Brown Rice Varieties Based on Aroma Extract Dilution Analyses

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The aroma compounds present in cooked brown rice of the three varieties Improved Malagkit Sungsong (IMS), Basmati 370 (B 370), and Khaskhani (KK), and of the variety Indica (German supermarket sample), were identified on the basis of aroma extract dilution analyses (AEDA). A total of 41 odor-active compounds were identified, of which eleven are reported for the first time as rice constituents. 2-Amino acetophenone (medicinal, phenolic), which was up to now unknown in rice aroma, exhibited the highest flavor dilution (FD) factor among the 30 to 39 odor-active compounds detected in all four varieties. 2-Acetyl-1-pyrroline, exhibiting an intense popcorn-like aroma-note, was confirmed as a further key aroma constituent in IMS, B 370, and KK, but was not important in Indica. Differences in the FD factors between the varieties were found for the previously unknown rice aroma compound 3-hydroxy-4,5-dimethyl-2(5H)-furanone (Sotolon; seasoning-like), which was higher in B 370 than in IMS and KK. In IMS, a yet unknown, spicy smelling component with a very high FD factor could be detected, which contributed with lower FD factors to the overall aromas of B 370 and KK, and was not present in Indica. The latter variety, which was available on the German market, differed most in its overall aroma from the three Asian brown rices.

KEYWORDS: Rice aroma; 2-acetyl-1-pyrroline; 2-amino acetophenone; aroma extract dilution analysis

INTRODUCTION

Identification of volatile compounds present in different varieties of cooked rice has been the topic of a number of investigations (*1*−*8*), and up to now more than 200 volatiles have been reported (*9*). In certain varieties, called scented or aromatic rices, the intensely popcorn-like smelling 2-acetyl-1-pyrroline (ACPY) was identified by Buttery and co-workers (*1*) about 20 years ago. Because of its extremely low odor threshold of 0.1 μg/kg in water, ACPY has been suggested as the characteristic compound of aromatic brown rice (*2*). 2-Acetyl-1-pyrroline has also been characterized as the key odorant responsible for the roasty, popcorn-like aroma of freshly baked wheat bread crust (*10*), freshly popped corn (*11*), and cooked pandan leaves (*12*), and was suggested as an important contributor to the smell of tiger's urine (*13*).

The first systematic approach to examine the contribution of the entire set of volatiles to the aroma of rices was done by Buttery et al. (*5*) on cooked California long-grain rice. On the basis of odor activity values calculated by dividing the concentrations by the odor thresholds, the authors confirmed ACPY, (E,E)- deca-2,4-dienal, nonanal, hexanal, (E)-non-2-enal, octanal, decanal, 4-vinyl-2-methoxyphenol, and 4-vinylphenol as the most important among the 64 odorants identified.

Quantitations of 2-acetyl-1-pyrroline in different aromatic rices (*14*) have confirmed the very high flavor contribution of ACPY to all rice aromas. Paule and Powers (*6*) also found a positive correlation of ACPY with the overall aromas of several aromatic rices. Further studies have shown that the level of ACPY in scented rice is affected by factors such as farm location (*15*), ripening and drying temperatures (*16*), as well as storage or aging (*17*, *18*).

Based on an overall sensory evaluation, Nagaraju et al. (*19*) classified the scent of 16 aromatic varieties into three distinct types: (A) Basmati 370 and Pakistan Basmati; (B) Malagkit Sungsong; and (C) small-grained rices such as Badshabhog, Krishnabhog, Haldigudhi, and Marasingbhog from Bangladesh. It is, however, not yet clear whether differences in ACPY concentrations, or the presence of a different set of odorants, are responsible for such aroma differences.

The purpose of the present investigation was, therefore, to evaluate the flavor contribution of the whole set of volatiles generated during cooking of four different rice varieties by means of aroma extract dilution analyses (AEDA). This method allows one to approximate the contribution of single odorants present in flavor extracts based on their thresholds in air (*20*). The varieties used were characterized by different methods to confirm their authenticity.

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MATERIALS AND METHODS

Rices. The following authentic brown rice samples representing the three different aroma types (*19*) were obtained: Improved Malagkit Sungsong from PhilRice (IMS, dehulled with Satake THU-35A dehuller), 370 Basmati (B 370) from Dr. G. S. Khush of IRRI Los Baños, and Khashkani (KK) from Dr. N. H. Choudhury and A. K. Khandker, Bangladesh Rice Research Institute, Gazipur, Bangladesh. Brown rice samples were kept in a freezer at −20 °C until processed for phytosanitary clearance and then airfreighted to Germany.

The rices were classified by the seedling isozyme technique of Glaszmann (*21*) at the isozyme Laboratory of IRRI. B 370 was classified as belonging to group V, and KK and IMS were found to belong to group VI (japonica). Length and length/width of 10 grains of brown rice were measured with a photoenlarger magnifying 10×. A sample of brown rice was milled in a Kett micromill and analyzed for alkali spreading value. Milled rice was ground with a Udy Cyclone mill with 60-mesh sieve and analyzed for apparent amylose content (*22*) and gel consistency (*23*).

Rice of the variety Indica was purchased in a local supermarket in Germany, and the identity was confirmed by the supplying company.

Chemicals. Reference compounds were obtained commercially (numbers refer to compound names in the tables): nos. 1, 18, 48 (Merck, Darmstadt, Germany); nos. 2, 4, 6, 10−12, 14−16, 19−22, 25−27, 29, 32−35, 38, 40, 42, 45−47 (Aldrich, Steinheim, Germany); nos. 3, 23, 28 (Fluka, Neu-Ulm, Germany); nos. 5, 39, 43 (Lancaster, Mühlheim am Main, Germany); and no. 30 (Roth, Karlsruhe, Germany). (*Z*)-Dec-2-enal (no. 17) was isolated by HPLC from commercial (*E*)-dec-2-enal and the (*Z*)-configuration of the double bond was confirmed by ^{1}H NMR spectroscopy. The following were synthesized according to the literature references given in parentheses: 2-Acetyl-1-pyrroline (no. 7; *1*), non-1-en-3-one (no. 8; *24*), 2-methoxy-3,5-dimethylpyrazine (no. 9; *25*), (*Z*)-non-2-enal (no. 13; *26*), (*E*,*Z*)-deca-2,4-dienal (no. 24; *27*) 4,5- epoxy-(*E*)-dec-2-enal (no. 31; *28*) and bis-2-methyl-3-furyl-disulfide (no. 37; *29*).

Preparation of the Aroma Extracts. Brown rice (10 g) was boiled for 25 min in tap water (20 mL). The freshly cooked rice was immediately frozen in liquid nitrogen, and, after addition of anhydrous Na_2SO_4 (60 g), the frozen rice was powdered by means of a Waring blender. The material was suspended in dichloromethane (200 mL) and stirred for 1 h. Extraction was repeated twice using 100 mL of dichloromethane each time. The combined extracts were dried over anhydrous Na_2SO_4 and concentrated to 100 mL by distilling off the solvent at 47 °C using a Vigreux column (50 × 1 cm). The volatile fraction was isolated by high-vacuum distillation using the solvent assisted flavor evaporation technique (*30*). For aroma extract dilution analysis (AEDA), the distillate was finally concentrated to 1.0 mL by distilling off the solvent by means of a Vigreux column at 47 °C, followed by microdistillation (*9*).

High-Resolution GC/Olfactometry (HRGC/O) and High-Resolution GC/Mass Spectrometry (GC/MS). HRGC/Olfactometry was performed by means of a type 5300 Mega Series gas chromatograph (Carlo Erba Instruments, Hofheim, Germany) and by using the following capillaries: FFAP (free fatty acid phase; 30 m × 0.25 mm i.d. fused silica capillary, 0.25 µm; J & W Scientific, Fisons, Germany), DB-5 (30 m × 0.32 mm i.d. fused silica capillary, 0.25 µm; J & W Scientific), and DB-1701 (30 m × 0.32 mm i.d. fused silica capillary, 0.25 µm; J & W Scientific). The samples were injected onto the GC column by the cold on-column technique at 40 °C. After 1 min, the temperature of the oven was raised at 40 °C/min to 50 °C, held for 2 min isothermally, then raised at 6 °C/min to the final temperature of 240 °C. The flow rate (1.5 mL/min) of the carrier gas helium was split 1:1 (by volume) at the end of the capillary into an FID and a sniffing port, both held at 200 °C. Linear retention indices (RIs) were calculated using *n*-alkanes as the reference (*10*). Mass spectrometry (MS) was performed by means of an MAT 95 S (Finnigan, Bremen, Germany) in tandem with the capillaries described above. Mass spectra in the electron impact mode were generated at 70 eV. Chemical ionization was performed at 115 eV using isobutane as the reactant gas.

GC/Olfactometry and Aroma Extract Dilution Analysis (AEDA). The original flavor extract (1 mL out of 10 g of rice) was analyzed by GC/Olfactometry using at least four panelists recruited from the German Food Research Institute. This number of panelists was found to be necessary so as to not overlook odor-active areas during the sniffing procedure. Odor qualities of the compounds eluting from the GC column were compared based on a standard mixture of 60 reference odorants having defined odor qualities (e. g., hexanal (green), 3-methylbutanal (malty), 2-acetyl-1-pyrroline (popcorn-like), etc.). The panelists were also asked to rank the intensities of the perceived odors on a scale from 0.5 to 3.0.

Determination of the flavor dilution (FD) factors was then done by the three panelists having detected the highest number of odor-active areas and with the highest intensity, respectively. The FD factors of the odor-active compounds were determined by HRGC/O of the following dilution series (*10*): the original extract was diluted stepwise with dichloromethane (1:1 by volume). HRGC/O was then performed with aliquots (0.5 µL) using capillary FFAP. The results, differing by not more than 2 FD factors, were averaged.

Table 1. Physicochemical Properties of the Rice Varieties Improved Malagkit Sungsong (IMS), Basmati 370 (B 370), Khashkani (KK), and Indica (IND) (classification in B, A, and C according to ref. *19*)

property	IMS	B 370	KK[a]	IND
grain length (mm)	5.0	6.8	4.3	6.9
grain length-width ratio	1.8	3.4	2.2	3.4
classification according to (*21*)	VI	V	VI	–[b]
milled rice				
apparent amylose content (AC; %)	5.6	21.5	23.6	20.6
alkali spreading value	6.0	5.1	6.0	6.4
gel consistency (mm)	67	69	38	61

[a] Badshabhog type. [b] Classification was not possible because the sample did not germinate.

RESULTS AND DISCUSSION

To characterize the rice varieties from the botanical and technological points of view some of their properties were determined by physicochemical methods. Basmati 370 (B 370) had long and slender grains. Improved Malagkit Sungsong (IMS) and Khashkani (KK) had shorter and wider grains (**Table 1**). Isozyme classification according to ref *21* showed group V for B 370 and group VI (japonica) for IMS and KK. IMS was classified as waxy contaminated with some translucent grains, which explained the higher than 2% apparent amylose (AC in **Table 1**). KK had the typical low gelatinization temperature (GT) as shown by alkali spreading value of 6, and soft (61−100 mm) gel consistency. Earlier samples of Malagkit Sungsong had 1.2−5.0% amylose (*31*).

B 370 had intermediate amylose and GT and a soft gel consistency. Basmati 370 grown in the Punjab region of Pakistan had 21−26% amylose, alkali spreading value of 3−7, and gel consistency of 35−74 mm (*31*). Khashkani had close to high amylose, low GT, and hard gel consistency, just like Badshabhog (25% amylose and alkali spreading value of 6.5; (*31*)). Hence, the samples had typical quality characteristics of their variety types.

In the first experiment, IMS was cooked, and the volatiles were immediately isolated by solvent extraction and careful high-vacuum distillation (at 30 °C) of the extract. This procedure was used to avoid formation of additional amounts of flavor compounds. For example the formation of 2-acetyl-1-pyrroline during workup may occur if the simultaneous steam distillation/extraction is used to isolate volatiles from foods (*32*).

Application of GC/Olfactometry to the aroma extract revealed 38 odor-active areas in the gas chromatogram (**Table 2**). However, sniffing of serial dilutions in AEDA showed that most of the odorous areas were not very potent, because only 12

Table 2. Odor-Active Volatiles (FD ≥ 1) in Cooked Brown Rice of the Variety Improved Malagkit Sungsong (IMS)

no.	odorant[a]	odor quality[b]	RI on FFAP	DB-5	DB-1701	FD factor[c]
1	butan-2,3-dione	buttery	985	<600	700	2
2	hexanal	green	1089	800	885	2
4	octanal	citrus-like	1284	1000	1087	1
5	oct-1-en-3-one	mushroom-like	1300	981	1076	4
6	2-methyl-3-furanthiol[d]	meaty, sulfurous	1319	nd[e]	917	1
7	2-acetyl-1-pyrroline	popcorn-like	1330	920	1017	1024
9	2-methoxy-3,5-dimethylpyrazine[d,f]	earthy	1423	1054	1117	4
10	acetic acid	sour	1443	600	790	1
11	methional[d]	cooked potato	1454	902	1042	4
12	decanal[d]	soapy	1492	1206	nd[e]	2
13	(*Z*)-non-2-enal[d]	fatty, green	1500	1146	1254	2
14	2-isobutyl-3-methoxypyrazine[d,f]	earthy, green bell pepper	1514	1180	1240	16
15	(*E*)-non-2-enal	fatty, tallowy	1529	1165	1272	8
16	(*E*,*Z*)-nona-2,6-dienal[f]	cucumber-like	1580	1155	1262	1
17	(*Z*)-dec-2-enal[d]	fatty, green	1605	1253	1357	2
18	butanoic acid	sweaty, rancid	1625	815	995	1
19	phenylacetaldehyde	honey-like	1642	1040	nd[e]	1
20	2- and 3-methylbutanoic acid	cheese-like, sweaty	1660	858	1057	4
21	(*E*,*E*)-nona-2,4-dienal	fatty	1698	1217	1349	4
22	pentanoic acid	sweaty	1724	926	1104	1
23	unknown	medicinal, metallic	1734	1187	1285	8
25	(*E*,*E*)-deca-2,4-dienal	fatty	1800	1318	1448	16
27	2-methoxyphenol	smoky	1858	1088	1230	4
28	2-phenylethanol	honey-like	1908	1116	1278	8
31	4,5-epoxy-(*E*)-dec-2-enal	metallic	2000	1380	1555	128
32	4-hydroxy-2,5-dimethyl-3(2H)-furanone[d]	caramel-like	2027	1077	1260	8
36	unknown ("ISMX")	spicy	2132	nd[e]	nd[e]	2048
37	bis-(2-methyl-3-furyl)-disulfide[d,f]	meaty	2150	1527	1615	2048
38	3-hydroxy-4,5-dimethyl-2(5H)-furanone[d,f]	seasoning-like	2197	1122	1370	32
39	4-vinyl-2-methoxyphenol	spicy, clove-like	2203	1313	1484	32
40	2-amino acetophenone[f]	medicinal, phenolic	2222	1306	1478	2048
41	3a,4,5,7a-tetrahydro-3,6-dimethyl-2(3H)-benzofuranone[d,f]	sweet, spicy	2235	1456	1683	8
42	5-ethyl-3-hydroxy-4-methyl-2(5H)-furanone[d,f]	seasoning-like	2263	1227	1436	1
43	4-vinylphenol	phenolic	2397	1237	1500	16
45	indole	sweet, burnt	2456	1300	1542	4
46	3-methylindole[d]	mothball-like	2504	1394	1622	2
47	phenylacetic acid[f]	honey-like	2557	1267	1524	16
48	vanillin	vanilla-like	2573	1410	1640	128

[a] The compound was identified by comparing it with the reference substance on the basis of the following criteria: retention index (RI) on the three stationary phases given in the table, mass spectra obtained by MS (EI), and odor quality as well as odor intensity perceived at the sniffing port. [b] Odor quality perceived at the sniffing port. [c] FD: Flavor dilution factor. An FD factor <1 means that the respective compound was not detected during sniffing of the undiluted extract. [d] The MS signals were too weak for an unequivocal interpretation. The compound was identified by the remaining criteria given in footnote *a*. [e] Not determined. [f] Identified for the first time as volatile constituent in cooked rice.

compounds exceeded an FD factor of 8 (nos. 7, 14, 25, 31, 36, 37−40, 43, 47, and 48; **Table 2**).

Results of the identification experiments performed by using either commercially available or synthesized reference odorants revealed that among them 2-amino acetophenone (no. 40), bis-(2-methyl-3-furyl)disulfide (no. 37), and an unknown compound exhibiting a spicy odor note (no. 36), had the highest FD factors and are reported here for the first time as constituents of scented rices. Unfortunately, attempts to identify the third compound ("IMSX") failed because it had an extremely low odor threshold and no mass spectrum could be obtained even when 1 kg of rice was worked up. ISMX (no. 36) did not exhibit a popcorn-like odor. Although actively looked for, compound 36 was also not identical with any odor-active compound produced by a Maillard-type reaction of proline with sucrose (data not shown). This procedure has earlier been suggested to generate compounds mimicking the aroma of Indian fragrant rices (*34*).

2-Acetyl-1-pyrroline contributed with a somewhat lower FD factor of 1024, thereby confirming its key role in brown rice aroma. With clearly lower aroma contributions, 4,5-epoxy-(*E*)-dec-2-enal (no. 31; metallic) and vanillin (no. 48; vanilla-like) were identified, followed by 3-hydroxy-4,5-dimethyl-2(5H)-furanone (no. 38; seasoning-like; Sotolon) and 4-vinyl-2-methoxyphenol (no. 39; clove-like), with quite low FD factors. Besides Sotolon, another nine compounds are reported here for the first time as rice aroma compounds (see footnote *f* in **Table 2**).

In further experiments, the volatiles formed after cooking of the two other brown rice varieties (B 370 and KK) and of the variety Indica were isolated and evaluated by AEDA. In **Table 3** the results of the GC/O experiments are contrasted. In B 370, 39 odor-active compounds were detected, but only 10 of these odorants exceeded an FD factor of 8. Among them, 2-amino acetophenone (no. 40) and 3-hydroxy-4,5-dimethyl-2(5H)-furanone (no. 38) appeared with the highest FD factors (FD = 1024), followed by 2-acetyl-1-pyrroline (no. 7) and bis-(2-methyl-3-furyl)disulfide (no. 37). Somewhat lower odor activites were found for vanillin, 4,5-epoxy-(*E*)-2-decenal, and the unknown compound no. 36 which had flavor properties identical to those of IMSX (no. 36; **Table 2**).

In Khashkani (KK), 37 odor-active areas were detected, but again only 10 compounds showed FD factors higher than 8 (**Table 3**). Besides 2-amino acetophenone, 2-acetyl-1-pyrroline was identified as the second important odorant. Lower FD factors were exhibited by bis-(2-methyl-3-furyl)disulfide, the unknown IMSX, and 4,5-epoxy-(*E*)-2-decenal.

Table 3. Odor-Active Compounds (FD ≥ 1) Identified in the Varieties Basmati 370 (B 370), Khashkani (KK), and Indica (IND)[a]

			RI on			FD factor in[c]		
no.	odorant[a]	odor quality[b]	FFAP	DB-5	DB-1701	B 370	KK	IND
1	butan-2,3-dione	buttery	985	<600	700	4	2	2
2	hexanal	green	1089	800	885	2	2	4
3	(*Z*)-hex-3-enal[f]	green, leaf-like	1143	800	884	1	<1	<1
4	octanal	citrus-like	1284	1000	1087	2	2	2
5	oct-1-en-3-one	mushroom-like	1300	981	1076	4	8	2
7	2-acetyl-1-pyrroline	popcorn-like	1330	920	1017	512	512	2
8	non-1-en-3-one[d]	mushroom-like	1396	1084	1164	1	<1	<1
9	2-methoxy-3,5-dimethylpyrazine[d,f]	earthy	1423	1054	1117	<1	1	<1
10	acetic acid	sour	1443	600	790	1	<1	1
11	methional[d]	cooked potato	1454	902	1042	8	8	2
12	decanal[d]	soapy	1492	1206	nd[e]	<1	2	<1
13	(*Z*)-non-2-enal[d]	fatty, green	1500	1146	1254	4	2	1
14	2-isobutyl-3-methoxypyrazine[d,f]	earthy, green bell pepper	1514	1180	1240	8	4	<1
15	(*E*)-non-2-enal	fatty, tallowy	1529	1165	1272	8	16	8
16	(*E*,*Z*)-nona-2,6-dienal[f]	cucumber-like	1580	1155	1262	2	<1	<1
17	(*Z*)-dec-2-enal[d]	fatty, green	1605	1253	1357	2	2	1
18	butanoic acid	sweaty, rancid	1625	815	995	1	<1	<1
19	phenylacetaldehyde	honey-like	1642	1040	nd[e]	1	1	<1
20	2- and 3-methylbutanoic acid	cheese-like, sweaty	1660	858	1057	2	2	4
21	(*E*,*E*)-nona-2,4-dienal	fatty	1698	1217	1349	4	8	2
22	pentanoic acid	sweaty	1724	926	1104	1	1	1
23	unknown	medical, metallic	1734	1187	1285	<1	2	<1
24	(*E*,*Z*)-deca-2,4-dienal[d,e]	fatty, green	1753	1292	1407	<1	4	<1
25	(*E*,*E*)-deca-2,4-dienal	fatty	1800	1318	1448	16	32	16
26	hexanoic acid	sweaty	1832	1005	1194	1	<1	<1
27	2-methoxyphenol	smoky	1858	1088	1230	2	2	1
28	2-phenylethanol	honey-like	1908	1116	1278	2	4	1
29	γ-octalactone	coconut-like	1921	1260	1472	<1	<1	2
30	β-ionone	violet-like	1934	1491	1603	1	1	
31	4,5-epoxy-(*E*)-dec-2-enal[f]	metallic	2000	1380	1555	64	128	128
32	4-hydroxy-2,5-dimethyl-3(2H)-furanone[d]	caramel-like	2027	1077	1260	8	8	2
33	γ-nonalacton	coconut-like	2033	1361	1574	<1	<1	1
34	4-methylphenol	phenolic	2076	1091	1313	2	2	1
35	3-methylphenol	phenolic	2089	1102	1329	1	<1	<1
36	unknown	spicy	2132	nd[e]	nd[e]	64	256	<1
37	bis-(2-methyl-3-furyl)-disulfide[d,f]	meaty	2150	1527	1615	256	256	<1
38	3-hydroxy-4,5-dimethyl-2(5H)-furanone[d,f]	seasoning-like	2197	1122	1370	1024	16	32
39	2-methoxy-4-vinylphenol	spicy, clove-like	2203	1313	1484	32	16	32
40	2-amino acetophenone[f]	medicinal, phenolic	2222	1306	1478	1024	1024	512
41	3a,4,5,7a-tetrahydro-3,6-dimethyl-2(3H)-benzofuranone[d,f]	sweet, spicy	2235	1456	1683	4	1	<1
42	5-ethyl-3-hydroxy-4-methyl-2(5H)-furanone[d,f]	seasoning-like	2263	1227	1436	<1	2	<1
43	4-vinylphenol	phenolic	2397	1237	1500	<1	1	1
44	unknown	fruity	2400	nd[e]	nd[e]	4	<1	<1
45	indole	sweet, burnt	2456	1300	1542	8	2	1
46	3-methylindole[d]	mothball-like	2504	1394	1622	4	4	1
47	phenylacetic acid[f]	honey-like	2557	1267	1524	32	4	32
48	vanillin	vanilla-like	2573	1410	1640	128	64	256

[a] For footnotes see **Table 2**.

On the German market, several types of brown rices are sold. However, after cooking, the overall aroma was found to be much different from those of the three Asian varieties. By application of the AEDA on the volatiles generated after cooking of a brown rice assigned as "Indica", 29 odor-active compounds were detected (**Table 3**), among which only seven compounds exceeded an FD factor of 8. 2-Amino acetophenone and vanillin showed the highest FD factors, followed by 4,5-epoxy-(*E*)-2-decenal. Somewhat lower FD factors were determined for 4-vinyl-2-methoxyphenol, phenylacetic acid, and 3-hydroxy-4,5-dimethyl-2(5H)-furanone. By contrast, 2-acetyl-1-pyrroline contributed little, and bis-(2-methyl-3-furyl)disulfide and the IMSX did not contribute to the overall aroma of the Indica rice.

If one compares those aroma compounds exceeding an FD factor of 32 in at least one of the four varieties (**Table 4**), it becomes obvious that 2-amino acetophenone and 2-acetyl-1-pyrroline are the most important odorants in all three brown rice varieties (IMS, B370, and KK). Differences, however, show up for bis(2-methyl-3-furyl)disulfide and the unknown IMSX, both of which were higher in IMS. On the other hand, 3-hydroxy-4,5-dimethyl-2(5H)-furanone was much higher in Basmati 370 than in the two other varieties. A clear difference could also be observed for 4-vinylphenol, which was highest

Table 4. Comparison of the Most Important Odorants Showing an FD Factor ≥ 32 in at Least One Rice Variety

		FD factor in			
no.	odorant	IMS	B 370	KK	IND
7	2-acetyl-1-pyrroline	1024	512	512	2
25	(*E*,*E*)-deca-2,4-dienal	16	16	32	16
31	4,5-epoxy-(*E*)-dec-2-enal	128	64	128	128
36	unknown ("IMSX")	2048	64	256	<1
37	bis-(2-methyl-3-furyl)-disulfide	2048	256	256	<1
38	3-hydroxy-4,5-dimethyl-2(5H)-furanone	32	1024	16	32
39	2-methoxy-4-vinylphenol	32	32	16	32
40	2-amino acetophenone	2048	1024	1024	512
47	phenylacetic acid	16	32	4	32
48	vanillin	128	128	64	256

in IMS. Compared to the brown rices, the variety Indica was much lower in 2-acetyl-1-pyrroline, bis(2-methyl-3-furyl)-disulfide, and the unknown ISMX. On the other hand, 2-amino acetophenone and 4,5-epoxy-(*E*)-dec-2-enal were present with similar odor activities. The data suggest 2-amino acetophenone and 4,5-epoxy-(*E*)-2-decenal as important previously unknown rice aroma constituents. These compounds are also present in brown rices available in Europe. On the other hand, the data showed that 2-acetyl-1-pyrroline is a key odorant in brown rices, but only in those available in Asia.

During AEDA, the odor contribution of single odorants is ranked on the basis of odor thresholds in air. However, in the rice itself, the volatility or odor contribution, respectively, is influenced by the matrix, which is mainly starch and water. So, to establish the differences observed in the overall evaluation of the cooked rices, quantitative measurements and sensory experiments to mimick the overall rice aroma by flavor recombination experiments (*19*) are underway.

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